STYLE CHARACTERISTICS OF SCULPTURES DESCRIBED WITH THE DISTRIBUTION OF FACET NORMAL VECTORS OF A POLYGON MESH

A Form Comparison of Historical Wood Carvings by Takeshi Ihachi and Goto Yoshimitsu

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Abstract: This paper proposed a quantitative approach to comparing differences in the style characteristics of historical wood sculptures created by Ihachi and Yoshimitsu, two famous Edo-period carvers in the Kanto region of Japan. We remeshed 3D-scanning models of the sculptures to low-polygon models with the same number of polygons in order to quantitatively compare the models in a topological analysis, and defined the facet normals for each polygon mesh. We then plotted the facet normals of the low-polygon models to a unit sphere and plotted the density of the endpoints of the facet normals on the unit sphere in the spectrum. Several small areas with a very high density of endpoints could be observed on the Ihachi sphere, whereas, for Yoshimitsu, endpoint density appeared to be lower and less concentrated. Thus, it was determined that the surfaces of Ihachi's sculptures tend to orient to several specific directions, while the surfaces of Yoshimitsu's sculptures orient to various directions equally.

Keywords: Historical Wood Sculpture, Style Characteristic, Polygon Mesh, Facet Normal

1. Introduction

Ornate wood carving decorations are considered one of the main features of the architecture of Edo-era temples and shrines [1]. A large number of beautiful wood carvings from this period can be found in existing temples and shrines in Chiba Prefecture. To preserve and exhibit these historical artifacts, and to analyze the artistic techniques of the ancient sculptors who produced them, we spent three years collecting 3D digital models of the first-generation wood sculptures of Takeshi Ihachiro Nobuyuki (1751-1824) and Goto Riheie Tachibana Yoshimitsu (1815-1902), both famous sculptors in Chiba Prefecture during the Edo period. The 3D models were captured directly by 3D scanning or generated from photographs in Autodesk Remake. During direct observation of the wood carvings and the 3D models, we noticed a distinct style difference between the two carvers' wooden sculptures. Although, according to the Tyoko-Hidarisi Gotosi Seikeizu (彫工左氏後藤氏世系図) [2], Takeshi Ihachi and Goto Yoshimitsu were only 50 years different in age, and their masters both followed the Murai Style, the visual difference between their sculptures is readily observable and easily recognized by art history researchers, active sculptors, and enthusiasts. Past studies on differences in styles have generally stopped at relatively qualitative descriptions. However, when it comes to aligning or restoring works based on such description, a strictly qualitative description may bring a degree of inaccuracy.

In recent years, the technology of 3D scanning and reverse engineering has been developed to record the features of the scanning target directly and accurately. Within these recording approaches, the conversion of 3D models from point clouds to polygon models has been a standard and efficient method for 3D scanning; determining how to measure and edit the scanning data became the next challenge. One of the required tasks involves the simplification of polygon meshes without a deterioration of the original shape (Figure 1). This simplification could not
only speed up the editing process, but also emphasizes the essential style characteristics (such as the outer contour, proportion, and primary shapes and composition.) of the form to be analyzed [3].

Although the simplification algorithms were basically applied in the reverse engineering of industrial production, the concept of simplifying forms to grasp style characteristics is also common in sculpting and painting. Simplifying a complex form into polyhedra form or a composition of geometrical elements (e.g., spheres, cubes, cylinders, etc.) is a fundamental and essential skill for designers and artists. In previous carving workshops, the rough carving that would mainly determine the style of the sculpture [4] was often completed by experienced masters. In this stage, the rough carving focused on the composition of the primary form and was closer to polyhedra without detail. Therefore, simplifying high-poly models into...
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Although the simplification algorithms were basically high-poly models by Ihachi and Yoshimitsu for analysis (Figure 2). According to past studies, Takeshi Ihachi is best known for his distinctive wave carvings [5], while Goto Yoshimitsu is known for his graceful wood dragon carvings [6]. Thus, the first set of comparisons in this study sought to compare the differences in the specific shapes in the two carvers' sculptures that represented their distinct styles. Ihachi's wave form was abstracted from his "Dragons of Heaven and Earth" in Fudo-do, Oyama-ji Temple. Goto Yoshimitsu's dragon form was extracted from the curled tail of the dragon in "The Dragon of a Hundred Styles" in the courtyard of Tsuruya Hachimangu Shrine. Both sculptures were completed when the carvers were in their early fifties and their styles had fully matured. Ihachi's wave shows a visual tendency toward the abstract Japanese wave pattern in which small plates with a wave contour are arranged in the form of lamination (Figure 3). The laminating wave plates advanced horizontally to the left and right, each with a clear and coherent wave form. Due to the laminating of the plates, the overall form of the wave shows a tendency of specific orientation. As for Yoshimitsu's work, though it is a relief, the curled tail and several parts of the dragon's body were carved as a solid carving, and the solidity is apparent from various angles (Figure 4). The form of the body and tail tends to be cylindrical, with a strong sense of muscle mass and no clear specific orientation in the large surface area.

The second set of comparisons is of two Kibana lions, which allows an examination of differences in style characteristics for the same theme. Ihachi's work is the A-type(吽) wooden nose of the Fudodo of Oyamaji. Yoshimitsu's work is the Un-type(吽) wooden nose of Tsuruya Hachimangu. When comparing the two works, the flat blockiness of the overall form of Ihachi’s lion is significantly stronger than in Yoshimitsu’s figure. In particular, the lion's forehead, jaws, and the form around the mouth are flatter, with a frontal and left-right orientation. The form of Yoshimitsu’s lion is more solid and round; the head and body have a strong sense of spherical composition, and the form of the mane is also spherical. The transition between the surfaces is round and smooth, emphasizing the natural sense of volume. The primary surfaces do not have a strong sense of flatness or any specific orientation.

From direct observation, we learned that the observation of a sculpture should begin with the whole form and that the observer should not be drawn only to certain parts of the
sculpture. This offers a better way to accurately grasp the composition and the orientations of the surfaces in the primary form. This awareness of total control is also consistent with the study of modeling in fine arts. For example, when analyzing and copying the Greek Bust of Venus, inexperienced sculptors are often attracted by the form of a specific local area (such as the focal point area or the visual center that has been consciously created by the author), falling into the trap of trying to copy that part perfectly. Some become obsessed with the perfect reproduction of the front or side silhouette of the object and sculpt for too long a time at a certain angle rather than continually switching positions to observe the figure from different angles and adjusting the composition and transition of the surfaces. These misunderstandings may cause the sculptor to ignore the more important and fundamental principle of sculpture: the shaping of the existence of the mass and the volume [7]. This 3D sense originates from the invisible existence created by the sculptor in the early stage of the work, which is created by the corresponding orientation of several groups on the main surfaces. Therefore, when comparing differences in style characteristics, such as the distribution of the orientations of the surfaces, it is more important to grasp the whole relationship rather than to analyze a specific part separately.

3. Quantifying and Visualizing the Style Characteristic

According to our direct observation of the two groups of forms, we found that one significant difference between the modeling characteristics of Ihachi and Yoshimitsu was that the large surfaces of Ihachi’s form tended to be oriented in a few specific directions. In contrast, the form of Yoshimitsu’s sculptures tended to be a composition of spheres. In this research, we sought to develop a quantitative method based on the geometric characteristics of the point, line, and surface of low-poly models to visualize and compare the distribution of the directions in which the main surfaces of the sculptures were oriented.

3.1 Definition of the Polygon mesh

A polygon mesh usually consists of a number of triangles, quadrilaterals, or other simple convex polygons and other types of small planes. A single polygon consists of vertices, edges, and faces; the facet normal vector represents the direction in which the face orients [8]. In order to describe the morphological characteristics of the low-poly model quantitatively, it is necessary to select one or several essential constituent elements of the polygon mesh model as the basis for quantifying such characteristics. According to the definition of a polygon mesh, a polygon mesh in ASCII format consists of color information for the polygon as well as the geometric information used to define the polygon in a 3D coordinate system, which includes three (corresponding to a triangular mesh) or four vertices (corresponding to a quadrilateral mesh) for the XYZ axis coordinates and the facet normal information used to mark the orientation of the polygon. According to the style characteristics of Ihachi and Yoshimitsu described in section 2, the specific direction of the surfaces in Ihachi's modeling and the non-specific orientation of the face in Yoshimitsu's modeling are one of the obvious differences between the two carvers' works. Accordingly, we chose a facet normal that allowed us to quantitatively describe the orientation of each polygon in the low-poly model as a quantitative parameter to compare the differences in style characteristics between the two engravers.

3.2 Definition of Facet Normal Unit Sphere

Our method uses facet normal vectors to visualize and quantify the distribution of the directions in which the
primary surfaces of the sculpture are oriented. We abstracted all 3D coordinate values of the facet normal vectors of the polygons from the STL-ASCII data of the polygon object using R-studio. We then defined a mapping of normal vectors from the polygon mesh to a unit sphere in Matlab. In this mapping, every endpoint of the facet normal vector corresponds to a point on the unit sphere, while every starting point of the facet normal vector corresponds to the center of the unit sphere (Figure 5). Since each polygon responding to the facet normal vector is a regular triangle of the same size, the density of the endpoints on the unit sphere represents the concentration level of the normal vectors.

To make the distribution of endpoints on the surface of the unit sphere easier to observe, we used Bruno Luong's N-dimensional Histogram algorithm to calculate the density of the endpoints and used Gaussian smoothing to generate a color spectrum map of the density on the unit sphere. In the application of Bruno Luong's N-dimensional Histogram algorithm, the 3D space from -1 to 1 was divided into $n^3$ equal unit cubic spaces (Figure 6). The number of bisections of the Axis X, Y, Z was defined as parameter $n$. We then counted the number of endpoints in each unit cubic space (marked in a red frame on the right side of Figure 6). Figure 6 shows a case of quadrisection of the X, Y, Z axis when parameter $n = 4$ and the 3D space from -1 to 1 is divided into $4^3 = 64$ unit cubic spaces. We adopted the Gaussian smoothing method using a weighted average of the number of the endpoints contained in the cubic space and its surrounding cubic spaces to smooth the transition between different density colors. The number of points after Gaussian smoothing was defined as the density value in the unit cubic space. Finally, all points were color-marked according to the density value. Larger density values were marked in higher color temperatures (approaching red); lower density values were marked in lower color temperatures (approaching blue). By this method, the density of the endpoints was plotted in the spectrum on the unit sphere.

3.3 Application to ellipsoid and the semi-ellipsoid

We tested whether the normal vector unit sphere method would enable us to effectively quantify and visualize the overall face orientation of the model with an ellipsoid and a semi-ellipsoid model. We partially flattened the left side of the y-axis of an ellipsoid and recreated a more uniform polygon mesh on both the ellipsoid and the semi-ellipsoid, unifying the two models with 10,000 polygons consisting of regular triangle polygons having identical side lengths. Direct observation of the two models shows that the surface orientation of the ellipsoid is relatively uniformly distributed, while the “squashed” side of the semi-ellipsoid reveals a distinct and specific orientation. We projected all facet normal vectors of the polygon models on the unit sphere, as shown in Figure 7. The facet normal endpoints of the ellipsoid tends to be uniformly distributed on the unit sphere and has a low density. In contrast, the semi-ellipsoid has a significant high-density red area on the squashed side, with significant orientation in a particular direction, consistent with the direct observation.

4. Comparison of two groups of sculptures
Since there are often holes, self-intersecting polygons, and duplicated vertices caused by the small details in the initial high-poly model, as generated from the point cloud, we fixed the errors of the polygon mesh and decimated the number of polygons before we applied the geometrical analysis to the 3d models of the sculptures. The decimating process fixes the geometrical errors by removing the small details on the high-poly model and reduces the heavy calculation load in the analysis. In this study, we used vertex decimation to recreate a more uniform low-poly mesh model with fewer polygons in Geomagic Studio. This process produced a polygon mesh constructed with equilateral triangle polygons having average edge length. Since the new mesh vertices always lie on the original mesh, the new mesh is an accurate result.

As described in section 1, the form of a rough carving of a sculpture is similar to a low-poly model. It emphasizes the composition of the primary surfaces in the sculpture, presenting the orientations of the primary surfaces briefly and clearly. We created low-poly models with different numbers of polygons and compared the shapes of the low-poly models with photographs of actual rough carving models in the same theme to produce a low-poly model with a similar shape to the real rough carving models. We also used the curvature spectrum map to check whether the low-poly model retained the main geometrical characteristics of the original high-poly model.

As described below, areas of high-concave curvature are marked in red, and areas of high-convex curvature are marked in blue on the spectrum map. We compared the high-curvature areas of 3D models consisting of 140k, 60k and 10k polygons. The results showed that the areas of high-curvature maintain similar shapes (Figure 8).

According to the Curvature Spectrum Map, we finally chose 10,000 as the number of polygons in the low-poly model and produced the low-poly models for our analysis (Figure 9).

4.1 Density Distributions with different parameter $n$

We calculated the results of the distribution on the unit sphere with different values of parameter $n$, from 10 to 600. Some of the results showing a significant change in the color spectrum are presented in Figure 10 and Figure 11. The density distributions of the Ihachi sculptures are shown in the right column of Figures 10 and 11; the density
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increased. In the first set, comparing Ihachi’s wave and Yoshimitsu’s dragon tail, the difference in the distributions becomes apparent when the value of $n$ is more than 40. Beyond that point, the maximum density of Ihachi’s wave becomes much higher than the density of Yoshimitsu’s dragon (Figure 10). In the second set, comparing Kibana lions, the difference in the distributions becomes evident when the value of $n$ is approximately 80 to 100; here, the maximum density of Ihachi is roughly 1.5 times that of Yoshimitsu (Figure 11).

Based on our results, we noted that the distributions and the maximum densities of the Ihachi and Yoshimitsu figures changed in different ways when the value of parameter $n$ is increased. These different patterns of change could be used to confirm the difference in the distributions of the orientations of the Ihachi and Yoshimitsu sculptures.
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Accordingly, we chose the critical points where the difference in the distributions occurs as the value of parameter \( n \).

4.2 Density Sphere of Ihachi’s Wave and Yoshimitsu’s Dragon Tail

From the color distribution on the density unit sphere, we found a significant red high-density area for Ihachi’s wave. In contrast, for Yoshimitsu’s dragon tail, there was no significant red-orange high-density area. In the large water blue area, the density distribution is relatively uniform. The highest density in the area approaches 0.25 of Ihachi’s maximum density with the increase in parameter \( n \).

4.3 Density Sphere of the Lion Faces of Ihachi and Yoshimitsu

Results for the lion’s head comparisons are similar. As shown by the density unit sphere, there are two prominent red high-density areas and an orange area in Ihachi’s lion’s head form. In contrast, Yoshimitsu’s lion head has no red high-density areas; however, there are two yellowish medium-density areas facing the x-y axis at 45 degrees and -45 degrees, respectively. The highest density in the area approaches half of Ihachi’s maximum density with the increase in parameter \( n \).

5. Discussion

Based on the density distribution of facet normal vectors on the unit sphere, we established differences in the density distributions of the works of the two authors and a degree of similarity between the works of the same carver (Figure 12). Our findings were consistent with our direct observation, as reported in section 2.

5.1 Ihachi’s Sculptures

In section 2, we characterized Ihachi’s wave form as "the lamination of wave plates," which gives the form a strong orientation in a specific direction. The red area of high density in the facet normal sphere of Ihachi’s wave shows polygons concentrated in a specific direction—a finding that is highly consistent with our direct observation. In the case of Ihachi’s Kibana lion, our direct observation of the lion’s face led us to conclude that there was a distinct flatness in the form of the top of the head, the jaw, and the side faces, especially in the area around the mouth. The presence of four red areas with a high density in the facet normal sphere of Ihachi’s lion face showed a significant number of polygons in the overall form orienting towards the top, bottom and the left and right sides of the form, which is consistent with our direct observation. According to the distribution of the density of facet normal vectors of the two different thematic sculptures, the results reflect the distinctive specific orientation of the surfaces in the Ihachi form, which is manifested in the 2.5D form that tends to approach relief or the solid form with a hexahedral tendency.

The specific orientation in Ihachi’s sculptures might be related to the traditional Asian wood carving technique of reproducing rough sketches onto square wood at the early...
stage of sculpture. However, due to the limited sample size of the current analysis, this idea remains only speculative.

5.2 Yoshimitu’s Sculptures

As for Yoshimitsu’s sculptures, we noted in section 2 the obvious composition of the spherical features observed both in the dragon tail form and the head form of the Kibana lion. In the facet normal sphere of the dragon tail form, we found that the overall density tended to be uniform and low, which is consistent with our direct observation. In the density distribution of the lion’s head, although the overall density was relatively constant and low, there were two areas of medium density that were yellowish in color. These two regions are at an angle of 40-45° with the normal direction of the front view of the sculpture. This indicates the presence of oblique surfaces in the transition between the completely front-facing and completely side-facing faces in the model.

6. Conclusion

In this study, the orientation of the surfaces that can influence the primary form of a sculpture is transformed into facet normal vectors of a polygon mesh, which can then be analyzed quantitatively and visualized by projecting the facet normal vector of the whole polygon model onto a unit sphere. The density of the facet normal vector endpoints distributed on the unit sphere indicates the degree of concentration in the orientation of the surfaces. Using this approach, we confirmed differences in the orientation of faces in two sculptural forms carved by Takeshi Ihachi and Goto Yoshimitsu, as well as the similarity of such characteristics between different works of the same author. Both direct observation and the applied density analysis showed that the specific orientation of the surfaces of Ihachi’s sculptures is strong, a characteristic that can produce a unique style when expressing flat relief themes such as wave patterns. At the same time, it may also lead to a strong sense of six-sidedness as a cubic form in which the transition of the faces is not smooth and natural. In contrast, the density distribution of Yoshimitu's sculptures tends to be uniform, which clearly shows the importance that he attached to the changing transitions of surfaces in his forms and his awareness of creating a sense of volume by using different surfaces oriented in a variety of directions.

As a next step, we plan to use the quantitative approach proposed in this study to analyze and organize the forms of other themes of Takeshi Ihachi and Goto Yoshimitsu. In addition, we intend to develop a method for quantitatively analyzing other style features in the forms, such as lines and curves.

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References